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National Secondary Drinking Water Regulations

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These National Secondary Drinking Water Regulations are pursuant to Section 1412 of the Safe Drinking Water Act, as amended (42 U.S.C.300g-1). These regulations control contaminants in drinking water that primarily affect the aesthetic qualities relating to the public acceptance of drinking water. At considerably higher concentrations of these contaminants, health implications may also exist as well as aesthetic degradation. The regulations are not Federally enforceable but are intended as guidelines for the States.

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Preface

The National Secondary Drinking Water Regulations specify secondary maximum contaminant levels (SMCLs) which, in the judgment of the Administrator, are requisite to protect the public welfare. Contaminants covered by these regulations are those which may adversely affect the aesthetic quality of drinking water, such as taste, odor, color and appearance, and which thereby may deter public acceptance of drinking water provided by public water systems.

Secondary maximum contaminant levels (SMCLs) are established for chloride, color, copper, corrosivity, foaming agents, iron, manganese, odor, pH, sulfates, total dissolved solids and zinc. At considerably higher concentrations, these contaminants may also be associated with adverse health implications. These secondary levels represent reasonable goals for drinking water quality, but are not federally enforceable. Rather, they are intended as guidelines for the States. The States may establish higher or lower levels as appropriate to their particular circumstances dependent upon local conditions, such as unavailability of alternate raw water sources or other compelling factors, provided that public health and welfare are adequately protected. However, odor, color and other aesthetic qualities are important factors in the public's acceptance and confidence in the public water system; thus, States are encouraged to implement these SMCLs so that the public will not be driven to obtain drinking water from potentially lower quality, higher risk sources.

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National Secondary Drinking Water Regulations

§ 143.1 Purpose

This part establishes National Secondary Drinking Water Regulations pursuant to Section 1412 of the Safe Drinking Water Act, as amended (42 U.S.C. 300g-1). These regulations control contaminants in drinking water that primarily affect the aesthetic qualities relating to the public acceptance of drinking water. At considerably higher concentrations of these contaminants, health implications may also exist as well as aesthetic degradation. The regulations are not Federally enforceable but are intended as guidelines for the States.

§ 143.2 Definitions

(a) "Act" means the Safe Drinking Water Act as amended (42 U.S.C. 300f *et seq.*).

(b) "Contaminant" means any physical, chemical, biological, or radiological substance or matter in water.

(c) "Public water system" means a system for the provision to the public of piped water for human consumption, if such a system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year. Such term includes (1) any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system, and (2) any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system. A public water system is either a "community water system" or a "non-community water system."

(d) "State" means the agency of the State government which has jurisdiction over public water systems.

(e) "Supplier of water" means any person who owns or operates a public water system.

(f) "Secondary Maximum Contaminant Levels" means SMCLs which apply to public water systems and which, in the judgment of the Administrator, are requisite to protect the public welfare. The SMCL means the maximum permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system. Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition.

§ 143.3 Secondary Maximum Contaminant Levels.

The Secondary Maximum Contaminant Levels for public water systems are as follows:

Contaminant	*Level*
Chloride	250 mg/l
Color	15 Color Units
Copper	1 mg/l
Corrosivity	Non-Corrosive
Foaming Agents	0.5 mg/l
Iron	0.3 mg/l
Manganese	0.05 mg/l
Odor	3 Threshold Odor Number
pH	6.5-8.5
Sulfate	250 mg/l
Total Dissolved Solids (TDS)	500 mg/l
Zinc	5 mg/l

These levels represent reasonable goals for drinking water quality. The States may establish higher or lower levels which may be appropriate dependent upon local conditions such as unavailability of alternate source waters or other compelling factors, provided that public health and welfare are not adversely affected.

§ 143.4 Monitoring

(a) It is recommended that the parameters in these regulations should be monitored at intervals no less frequent than the monitoring performed for inorganic chemical contaminants listed in the National Interim Primary Drinking Water Regulations as applicable to community water systems. More frequent monitoring would be appropriate for specific parameters such as pH, color, odor or others under certain circumstances as directed by the State.

(b) Analyses conducted to determine compliance with § 143.3 should be made in accordance with the following methods:

(1) Chloride – Potentiometric Method, "Standard Methods for the Examination of Water and Wastewater," 14th Edition, p. 306.

(2) Color – Platinum-Cobalt Method, "Methods for Chemical Analysis of Water and Wastes," pp. 36-38, EPA, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 160-162, 14th Edition, pp. 64-66.

(3) Copper – Atomic Absorption Method, "Methods for Chemical Analysis of Water and Wastes," pp. 108-109, EPA, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 210-215, 14th Edition, pp. 144-147.

(4) Foaming Agents – Methylene Blue Method, "Methods for Chemical Analysis of Water and Wastes," pp. 157-158, EPA, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 339-342, 14th Edition, p. 600.

(5) Iron – Atomic Absorption Method, "Methods for Chemical Analysis of Water and Wastes," pp. 110-111, EPA, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 210-215, 14th Edition, pp. 144-147.

(6) Manganese – Atomic Absorption Method, "Methods for Chemical Analysis of Water and Wastes," pp. 116-117, EPA, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 210-215, 14th Edition, pp. 144-147.

(7) Odor – Consistent Series Method, "Methods for Chemical Analysis of Water and Wastes," pp. 287-294, EPA, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 248-254, 14th Edition, pp. 75-82.

(8) pH – Glass Electrode Method, "Methods for Chemical Analysis of Water and Wastes," pp. 239-240, EPA, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 276-281, 14th Edition, pp. 460-465.

(9) Sulfate – Turbidimetric Method, "Methods for Chemical Analysis of Water and Wastes," pp. 277-278, EPA, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 334-335, 14th Edition, pp. 496-498.

(10) Total Dissolved Solids – Total Residue Methods, "Methods for Chemical Analysis of Water and Wastes," pp. 270-271, EPA, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 288-290, 14th Edition, pp. 91-92.

(11) Zinc – Atomic Absorption Method, "Methods for Chemical Analysis of Water and Wastes," pp. 155-156, EPA, Office of Technology Transfer, Washington, D.C. 20460, 1974, or "Standard Methods for the Examination of Water and Wastewater," 13th Edition, pp. 210-215, 14th Edition, pp. 144-147.

Appendix A

Statement of Basis and Purpose for the National Secondary Drinking Water Regulations

The following concepts and rationale were used in arriving at the specific levels of the SMCLs and should enable those whose responsibility it is to interpret or apply the regulations to do so with understanding, judgment and discretion. The most recent reviews of aesthetic factors relating to drinking water quality were prepared by Zoetemann in "Sensory Assessment and the Chemical Composition of Drinking Water" and the National Academy of Sciences (NAS) in its report, "Drinking Water and Health" (1977). "Secondary Maximum Contaminant Levels" means SMCLs which apply to public water systems and which, in the judgment of the Administrator, are requisite to protect the public welfare. The SMCL means the maximum permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system. Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition.

Chlorides

The presence of too great a concentration of chloride ions in drinking water can result in two undesirable effects. First, the consumer may detect an objectionable taste in the water. Second, corrosion of the pipes in hot water systems may occur. Existing evidence suggests that consumers react to excessive amounts of chlorides by either treating the water themselves, or by rejecting the water supply. Therefore, a limit has been set for chloride ion concentration.

The literature contains a number of reports on the taste thresholds of various salts. Whipple[1], using a panel of 10 to 20 persons, found the detectable range of concentration of various salts to be as shown in Table 1. Richter and MacLean[2] studied the response of a larger panel to sodium chloride in distilled water. Table 2 summarizes their results.

Lockhart, Tucker, and Merritt[3] also studied the taste thresholds of the ions in distilled water by studying their effects on the flavor of brewed coffee. Using a triangular test with panels of 18 or more, they found results that are summarized in Table 3. In a triangular taste test, the panel members are asked to taste three samples. Two of the samples may contain

either the salt being tested or distilled water, while the third is different from the other two. The panel member is asked to identify the odd one. Using this test procedure, the threshold concentration is defined as the concentration at which the number of correct separations is 50% above the chance of probability of one-third separations (i.e., when two-thirds of the panel make the separations correctly).

Results shown in Table 1 and Table 3, which summarize the Whipple and Lockhart et al. studies, are in agreement, even though different methods were used for analysis. The Richter and MacLean study found thresholds considerably below those of the other two studies. All three studies support a secondary maximum contaminant level of 250 mg/1 for chloride.

Recently, Bruvold and his co-workers[4, 5, 6, 7] have studied the influence of mineralization on the taste of water. Much of their work has been on the influence of total dissolved solids, but they noted that major taste effects are produced by anions. Chloride produced an effect somewhere between the milder sulfate and the stronger carbonate.[6, 7]

In addition to the influence of mineralization on the taste of water, the deterioration of domestic plumbing and water heaters due to high concentrations of Total Dissolved Solids (TDS may contain 50% chlorides) should also be considered. According to Lawrence, the approximate life of domestic water heaters for 200 mg/1 TDS water (100 mg/1 of chlorides) ranged between 10 years and 13 years, but declining heater life as a function of increasing TDS was fairly uniform: about 1 year shortened life per 200 mg/1 additional TDS (100 mg/1 of chlorides)[8]. Mineralization can also affect other domestic plumbing and municipal waterworks equipment.

Values for maximum chloride concentrations in drinking water set by other agencies are as follows: World Health Organization's (WHO) International Standards – 200 mg/1[9]; WHO's European Standards – 200 mg/1[10]; USSR Standards – 500 mg/1[11]; proposed European Communities (EC) Standards – 200 mg/1[12]; and Food and Drug Administration's (FDA) Bottled Water Standards – 250 mg/1[13].

Chloride cannot be readily removed from drinking water without the use of distillation, reverse osmosis or electrodialysis which are effective but relatively expensive; thus, the use of an alternate source or blending is the most desirable approach.

Based upon the above experimental data and in agreement with the standards presented above, a secondary maximum contaminant level of 250 mg/1 was determined to prevent most aesthetic effects. Consumers may become accustomed to the taste of somewhat higher chloride levels, but the economic effects of these higher levels ought to be avoided.

Table 1 — Range of Concentration of Various Salts Detected by Taste in Drinking Water by Panel of 10 to 20 Persons

	Concentration Detected – mg/l			
	Median		Range	
	Salt	Anion	Salt	Anion
KCl	525	250	250-600	167-286
NaCl	300	182	200-450	121-274
$CaCl_2$	250	160	150-350	96-224
$MgCl_2$	500	372	200-750	149-560
Sea Water [1]	–	300	–	150-600

[1] In terms of mg/l chloride.
Source: Whipple, G.C., The Value of Pure Water. Wiley (1907).

Table 2 — Taste Threshold Concentrations of Panel of 53 Adults for NaCl

	Concentrations – mg/l					
	Mean		Median		Range	
	NaCl	Cl	NaCl	Cl	NaCl	Cl
Difference from distilled water noted	160	97	100	61	70-600	42-364
Salt taste identified	870	530	650	395	200-2500	120-1215

Source: Richter, C.P. and MacLean, A., "Salt Taste Threshold of Humans," American J. Physiol. Vol. 4, *126*: 1-6, May 1939.

Table 3 — Taste Threshold Concentration of Salt and Ions in Water

	Threshold Concentrations – mg/l		
	Salt	Cation	Anion
NaCl	345	135	210
KCl	650	340	310
$CaCl_2$	347	125	222

Source: Lockhart, E.E., Tucker, C.L. and Merritt, M.C. The Effect of Water Impurities on the Flavor of Brewed Coffee, Food Research, 20, 598-605 (1955).

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Color

Experience has shown that if the water is highly colored, many people will turn to alternative supplies that may be less safe, although the level of this parameter is not known to be a measure of the safety of water. However, color may be indicative of high organic chemical contamination, inadequate treatment, high disinfectant demand and the potential for production of excess amounts of disinfectant by-products. At least one State now maintains color among its primary standards.

Black and Christman[1] analyzed natural color causing solids extracted from a number of waters. They broadly classified these solids as aromatic, polyhydroxy, methoxy and carboxylic acids. Natural color is also often reported to be the result of fulvic and humic acid fractions in the water. Although these acids are similar, Packham[2] has collected data to show that a true chemical difference exists between the fulvic and humic fractions of color causing solids. Color in drinking water also results from the presence of metals such as copper, iron and manganese. The entire state-of-the-art and research needs in the area of color have been extensively reviewed by the American Water Works Association's Research Committee on Color Problems.[3,4]

Color becomes objectionable to a considerable number of people at levels over 15 color units (C.U.). At a level of 30 C.U., experts feel that color will be detectable by all and aesthetically displeasing to most. However, a color level of 5 C.U. will be noted by many when viewed in a filled bathtub, whereas a level of 3 C.U. will not be noticed.[5] Rapid changes in color levels may provoke more citizen complaints than a relatively high constant color level and treatment plant operators should seek to prevent or modify such changes in color levels where possible.

Color from industrial sources may present different problems in measurement and handling than color from natural sources. Synthetic, as well as natural colors, should be monitored following procedures given in *Standard Methods*.[6]

Values for maximum color levels in drinking water set by other agencies are as follows: WHO International Standards – 5 C.U.[7]; WHO European Standards – 5 C.U.[8]; proposed EC Standards – 20 C.U.[9]; and FDA Bottled Water Standards – 15 C.U.[10].

Treatment for the removal of color from drinking water depends on the nature of the colored material. Some color can be removed by conventional treatment (oxidation, flocculation, filtration), but some types of color may require activated carbon treatment.

Based upon the above data, a secondary maximum contaminant level of 15 C.U. was determined to represent a color level which would prevent the bulk of consumer complaints about colored water.

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Copper

Copper imparts some taste to water and can cause staining of porcelain. Physiologically, copper is important to human metabolism, and as such, small amounts are generally regarded as non-toxic. However, large doses may produce emesis, and prolonged oral administration may result in liver damage. Therefore, for aesthetic and physiological reasons, it is desirable to limit the concentration of copper in drinking water.

Copper is an essential and beneficial element in human metabolism, and it is well known that a deficiency in copper results in nutritional anemia in infants. The daily requirement for adults has been estimated to be 2.0 mg.[4] Children of preschool age require about 0.1 mg of copper daily for normal growth, and the average daily urinary excretion is in the order of 1.0 mg, with the remainder being eliminated in the feces. Because the normal diet provides only a little more than is required, an additional supplement from water would ensure an adequate intake. The distribution of copper in the body is fairly uniform, except for the liver where it appears to accumulate. The general health hazard from excess copper intake at a level of a few milligrams per liter appears to be small, but a few people are adversely affected by ingestion of even trace amounts of copper. This disorder of copper metabolism is called Wilson's disease and can be arrested by the use of chelating agents.[2]

The flurry of research during and following the acceptance of copper and copper alloys as piping materials created a large amount of data on the solubility and physiological effects of these metals, but relatively little on the resulting taste of the water. Schneider quoted the Prussian Hygienic Institute for Water, Soil, and Air in Berlin, which stated that it was possible that a copper concentration of 3 to 5 mg/l could affect the taste of water adversely. Schneider suggested a few years later that the admissable amount of copper in water be set at 5 mg/l, as a higher concentration would give the water a disagreeable taste. Spitta, critically reviewing the literature on the effect of copper on human health, stated that 2 mg/l of copper was a taste threshold concentration. Froboese, on the other hand, reported that 1.5 mg/l was the lowest concentration of copper that normally could be tasted.[1] Cohen found that individuals vary in the acuity of their taste perception, and the threshold of taste for copper varies from 1-5 mg/liter.[3] Based on this research a copper concentration of 1 mg/l is reasonable to insure the absence of astringent taste effects.

Another reason for limiting the concentration of copper in water is to avoid the staining of porcelain. Obrecht found that porcelain fixtures can be stained blue or blue-green by low concentrations of copper in water.[5] The National Academy of Sciences[2] (NAS) concluded that a copper content of 0.5 mg/l or less, in some soft waters, will cause staining of porcelain.

Green-stained drapes were also found in a Yale dormitory where the water copper level was 4 mg/l. This same water was responsible for imparting a green tint to the hair of silver blonde coeds. Determination of copper levels in their hair were found to be 1,042 ppm as opposed to normal values of 17-38 ppm.[6]

Low copper concentrations can also cause black and white photographic prints to turn brown during processing. Furthermore, Obrecht reported that copper concentrations greater than 1 mg/l can produce insoluble green "curds" by reacting with soap.[5] In 1961, of 163 interstate supplies, 70 percent contained less than 0.2 mg/l. Of the 100 largest cities in the U.S., 94 contained less than 0.1 mg/l.[4]

Values for maximum copper concentrations in drinking water set by other agencies are as follows: WHO International Standards – 0.05 mg/l[7]; WHO European Standards – 0.05 mg/l[8]; USSR Standards – 0.05 mg/l[9]; proposed EC Standards – 0.05 mg/l[10]; and FDA Bottled Water Standards – 1 mg/l.[11]

Since copper in drinking water usually results from the action of aggressive water on copper plumbing the copper content can be reduced by stabilizing the water.

The SMCL for copper was set at 1.0 mg/l because copper imparts a detectable taste in water to some people at 1.0 mg/l. This is in agreement with the Food and Drug Administration's value for copper at 1 mg/l.

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11. 21 CFR Part 103 – Quality Standards for Foods with no Identity Standards – Bottled Water. *Federal Register*, Vol. 44, No. 45, 12172, March 6, 1979.

Corrosivity

Corrosion is a very significant concern, not only affecting the aesthetic quality of the water, but also having serious economic impact and health implications. Corrosion products containing materials such as lead and cadmium have been associated with serious risks to the health of consumers of drinking water. A number of indices (such as the Langelier Index) are presently available for measuring the corrosivity of drinking water but a single universal index applicable to all situations is not yet generally available. For the present, the secondary regulations state that the water should be "non-corrosive," as determined by the State.

It has been estimated by Hudson and Gilcreas that the annual loss from water corrosiveness is about $375 million.[1] In addition to the loss of materials used to convey water, water leakage from deteriorating distribution systems can be substantial. In some instances, as much as 25 percent of the water leaving a treatment plant is lost before reaching the consumer.

The concentration of trace metals in water collected in distribution systems or at household taps is more relevant than raw water with respect to water quality. Corrosion in a distribution system may add trace metals to finished water before it reaches the consumer.

Corrosivity is a complex characteristic of water primarily related to pH, alkalinity, dissolved oxygen, total dissolved solids, and hardness.[2] Soft water tends to be more corrosive than hard water. As a result, certain trace metals are found in higher concentrations in soft water. Because of localized conditions, important variations in water quality will occur as a result of the corrosion of pipe materials as water passes through the distribution system. Water velocity can also play an important role in the erosion and corrosion of pipe materials.[2,3] In addition, stationary water in contact with pipes can have a significant effect on the dissolution of distribution system materials. Furthermore, seasonal changes affecting water quality will result in variations in the concentrations of dissolved pipe materials at the tap.

Common piping materials used in distribution systems are iron, steel, cement (reinforced concrete), asbestos-cement, and plastic. Lead, copper, zinc, and alloys such as brass, bronze and stainless steel may also be used in addition to ferrous metals in pumps, small pipes, valves and other appurtenances. Trace metals and asbestos may be contributed to the water by corrosion products or simply by solution of small amounts of metals with which the water comes into contact.

Corrosion in distribution systems will result in the increase in levels of toxic materials such as lead and cadmium. Products of corrosion present in the water can also cause turbid waters and promote deposits under stagnant conditions, thereby encouraging bacterial growth. The health related aspects of corrosion are dealt with in the primary drinking water regulations.[4,5] In addition to adverse health implications, corrosion will also effect the taste, color and the aesthetic acceptability of the water.

The most commonly used materials in distribution systems whose corrosion products adversely affect the aesthetic quality of waters are iron

and copper. Ferrous materials are used for distribution mains as well as for service lines and household plumbing. The use of copper for transporting water is limited to service lines and household plumbing.

Corrosion of iron in distribution systems will result in the deposition of ferric iron in the mains and pipes. Loosening of the deposits will cause red water at the tap, which in turn will impart color and taste to the water and will cause the staining of fixtures and laundry. A survey of 534 municipal water supply systems in 1969 revealed that 281 (52.6%) have had red water problems.[6]

Another serious problem encountered with the corrosion of iron is tuberculation. Tuberculation of the interior surface of pipes caused by corrosion will result in a loss of the carrying capacity of the water through the distribution system.[2] Resistance to flow is caused by the roughening of the interior surfaces of the pipes by the tubercules and by the reduction of the inner diameter of the pipe due to the deposition of the corrosion products. In order to overcome the loss of the carrying capacity, higher pressures have to be generated at the pumping stations, which in turn require additional energy. It has been shown by Hudson (1966) that the cost of transporting the water increases as the 1.85th power of the loss in efficiency of the pipe line, and the physical value of the installation decreases almost directly with the loss of the carrying capacity.[7]

Deposits of corrosion products from iron may also serve as a breeding ground for a number of life forms including bacteria, nematodes, small crustaceans and protozoa. In addition to the health hazards associated with these organisms, the presence of organic matter and the anaerobic conditions prevailing in tubercules and deposits, some of the bacteria present will inevitably reduce sulfates to hydrogen sulfide and other odorous products rendering the water aesthetically unacceptable.[8] In addition, the sulfate reducing organisms will aid the acceleration of corrosion. It has been shown that every milligram of sulfate reduced will cause the corrosion of 2 milligrams of iron.[9]

The effect of water quality on the corrosivity of iron, steel and galvanized steel has been categorized by Obrecht, et al., as shown in Table 1.

Table 1 — Potable water categorization is applicable to all metals for scaling but only to iron, steel (not stainless), and galvanized steel for corrosivity (Obrecht, et al., 1975).

Category	Calcium (Ca), ppm	Sulfate (SO_4), ppm	Silica ($Si0_2$), ppm	Dissolved oxygen, ppm	Character
1A	0-18	As found	0-15	1-10	Extreme corrosion hot and cold.
1B	0-18	0-25	0-15	0-1	Moderate corrosion hot and cold. Extreme corrosion with $CO_2 > 8$ ppm.
1C	0-18	0-60	> 15	1-5	Slight corrosion cold, considerable hot. Aggressiveness reduced and perhaps not troublesome due to natural $Si0_2$.
2A	18-35	> Ca but not < 25	0-15*	1-10	Considerable corrosion hot, moderate cold. May be slightly scale forming very hot.
2B	18-35	0-25	0-15	1-10	Moderate to slight corrosion hot and cold. May be scale forming hot.
2C	18-35	< Ca	> 15	1-8	Corrosion unlikely. May be scale forming hot.
2D	18-35	< Ca	As found	0-1	Corrosion unlikely. May be scale forming hot.
3A	35-75	< 1½ Ca	0-15	1-10	Moderate corrosion hot, slight cold. Considerable scale formation hot.
3B	35-75	> 1½ Ca	0-15	1-10	Considerable corrosion hot, slight cold. Considerable scale formation hot.
3C	35-75	< 1½ Ca	> 15	1-10	Considerable scale formation. Slight corrosion hot.
3D	35-75	As found	As found	0-1	Considerable scale formation. Corrosion unlikely.
3E	35-75	> 1½ Ca but < 3 Ca	> 30	1-10	Corrosion unlikely hot and cold. Excessive scale formation.
4A	> 75	< 2 Ca	0-30	1-10	Excessive scale formation. Corrosion unlikely to slight cold, slight to moderate hot.
4B	> 75	> 2 Ca	0-30	1-10	Excessive scale formation. Galvanic corrosion considerable hot and cold.
4C	> 75	< 3 Ca	> 30	1-10	Excessive scale formation. Corrosion unlikely.

*With SiO_2 over 15 ppm, corrosion may be reduced in proportion to $Si0_2$ content.

NOTES: Presence of chlorides in concentrations greater than 100 ppm, with high sulfates, renders a water more corrosive than indicated by category above. Presence of carbon dioxide in concentrations exceeding 5 ppm accelerates corrosion processes where category groups indicate corrosion. In concentrations exceeding 20 ppm, it may cause an indicated non-corrosive water to be corrosive.

TERMS: Extreme or excessive – where effects necessitate immediate corrective action.
Considerable – where corrective action is desirable.
Moderate – where corrective action is questionable and depends on economy affected.
Slight – where effect is too slight to warrant corrective action.
Unlikely – where effects are possible but not probable.

Source: Obrecht, Malvern F. and Myers, James R. "Potable Water Systems in Buildings: A Treatsie on Corrosion and Deposit Control, Materials Selection, System Design and Operation." Reinhold Publishing Co., 1975.

The presence of carbonate minerals will inhibit the corrosion of iron. In soft waters containing no calcium, this inhibition is the greatest at pH values ranging from 6.5 to 7.0 for mild steel, and 7.0 for cast iron provided the alkalinity is five or ten times above the chloride and sulfate salt concentration levels.[2] Studies by Larson indicated that in soft waters tuberculation of cast iron increased when the pH was increased within a range of 7.5 to 9.0.[2] The presence of calcium will also inhibit the corrosion of iron. It has been shown that in the presence of calcium combined with a minimum alkalinity of 50 to 100 mg/l, the life of mild steel will be extended considerably. In general, the greater the concentrations of calcium, the greater the protective action of the water. Larson also concluded that the combination of high alkalinity and calcium with the inherent low pH will prevent corrosion more easily than low alkalinity and calcium combined with high pH values.[2]

Corrosion products of copper also will adversely affect the aesthetic quality of water. The presence of excessive amounts of copper in water causes staining of fixtures,[3] imparts taste, causes soap curds[3] and in extreme instances, imparts green color to the hair of individuals who wash in such waters.[10]

The corrosion of copper relative to water quality has been well documented.[2,3] Results of a study by Obrecht, et al., relating to the corrosion of copper pipes indicated that pitting of copper will occur when in contact with cold water having a pH of less than 8.5, relatively low hardness, high carbon dioxide and oxygen content and a saturation index of slightly positive to strongly negative.[3] High concentrations of sulfates, chlorides, bicarbonates and total dissolved solids in the presence of dissolved oxygen and free carbon dioxide concentrations in excess of 10 mg/l will accelerate the corrosion of copper.

In a study evaluating the effect of various California waters on copper pipes, Cruse and Pomeroy[11] reported that in the majority of instances no pitting of copper occurred when copper was in contact with well waters having carbon dioxide levels of 5-10 mg/l. Table 2 summarizes the effect of various qualities of California waters on the corrosion of copper.

In Washington County, Maryland, 669 copper determinations at the tap were made in both public and private water systems.[12] Efforts were made to sample running water, rather than standing water in contact with plumbing systems overnight, because the latter has been shown to have greatly increased trace-metal concentrations in systems without corrosion control. The correlation coefficients of copper concentration with pH, with hardness, and with conductivity, were -0.369, -0.162-0.173, respectively; all were significant (p=0.01).

Velocity of the water can also significantly affect the rate of corrosion in copper pipes. Stagnant water conditions will promote concentration cell corrosion of metals and alloys, including copper in water distribution systems. Copper is also susceptible to erosion corrosion when exposed to high velocity and high temperature waters. Erosion corrosion of copper becomes a significant problem when the copper is in contact with soft waters moving at a rate over 4 feet per second, having a dissolved oxygen level exceeding 2 ppm and a carbon dioxide content over 10 ppm.

Table 2 — Characteristics of Waters in California Where Pitting of Copper Tubing Has Been Observed (Cruse and Pomeroy, 1974)

Location	pH	pHs	Ca	Mg	Na	K	Alk as $CaCO_3$	SO_4	Cl	NO_3	CO_2 Approx	Total Salts me/l
					Milligrams per liter							
A - Santa Susana	7.2	7.0	176	80	134	3	239	646	110	6	27	21.4
B - OCWWD # 4	(7.1)	6.9	226	42	162	7	291	527	175	0	40	21.8
C - Ventura	(7.1)	6.9	174	61	160	8	278	633	71	7	40	20.9
D - Bouquet Canyon	7.5	7.3	110	38	92	4	170	395	39	2	8	12.7
E - Valencia*	(7.2)	7.0	144	38	80	4	251	337	50	12	28	13.8
F - Santa Paula	7.2	7.0	134	36	103	6	250	372	47	0	28	14.4
G - Saticoy	7.2	6.9	150	54	144	6	291	559	67	6	32	18.9
H - Salinas	6.6	7.9	37	6	66	5	142	21	74	9	60	5.4
I - Corona†	7.0-7.5	7.1-7.5	112	24	90	5	237	180	113	48	8-40	12.0
J - La Crescenta	7.0	7.7	58	20	70	2	131	114	65	56	25	7.7
K - Fillmore	7.0	6.7	210	67	118	6	330	613	41	32	58	21.2
L - Pico Rivera	7.8	7.4	88	15	25	4	229	56	30	29	5	6.2
M - La Cumbre	7.2	7.0	138	46	108	3	380	308	87	1	21	15.2
N - Santa Maria	(7.2)	7.0	/	/			258		34		12	10
O - Carmarillo §	7.1	7.0	170	58	211	8	234	607	176	5	40	22.5
P - San Diego	Colorado River plus flood control reservoirs; some from wells in the earlier years											
Q - 1, Los Angeles**	8.2		49	16	169	5	119	295	99	3	2	22.6
Q - 2, Los Angeles††	8.3		26	6	36	4	115	27	18	1	1	6.9
Q - 3, Los Angeles//	7.7		65	16	48	4	153	122	39	8	5	13.6

* Average of two wells, showing TDS concentrations of 1,090 and 606 mg/l

† Average of water of varying composition from a single well

/ Total Hardness 377 mg/l

§ Pitting of copper was known in this system

** Partially softened Colorado River water, about 10 percent of total

†† Owens River water, about 70 percent of total

// Ground waters, about 20 percent of total

Source: H. Cruse and R. Pomeroy, "Corrosion of Copper Pipes." Journal of AWWA, 66, 481, August, 1974.

Copper-zinc alloys are also subject to dezincification which consists of the selective removal of zinc. Copper alloys such as muntz metal and yellow brass are particularly subject to dezincification when exposed to high temperature soft waters containing free carbon dioxide and a high chloride content. High pH levels (> 9.0 to 9.6) will also promote dezincification.[2] Lower zinc alloys usually are subjected to localized (plug type) dezincification when exposed to neutral, alkaline or slightly acidic solutions. On the other hand, higher content zinc alloys will be subject to uniform dezincifications.[3]

Corrosion protection of water distribution systems, in general, may be achieved by a number of methods including pH adjustment, addition of lime, increasing alkalinity, and addition of phosphates or silicates.[2]

The extent and type of treatment selected is dependent upon the characteristics of the water and the compatibility of treatment with regard to the various materials used to convey the water through the distribution system. It should be noted that corrosion control aimed at the reduction of contamination from one source may or may not reduce contamination originating from other sources as well. Experience indicates that among the previously mentioned treatment techniques corrosion control through the deposition of a protective calcium carbonate film on the interior surfaces of the conveyors of the water may be the most effective approach to non-selectively provide protection to a number of materials such as asbestos cement, lead, iron, galvanized steel, copper and various alloys that make up the distribution system. This method is widely applicable and extensively used.[15]

The AWWA indicates that the maintenance of calcium carbonate stability is the most effective method of preventing corrosive action on iron mains. AWWA recommends 80 mg/l hardness as $CaCO_3$ is best for a balance between scaling and corrosion characteristics, although a goal of 90 to 100 mg/l for some supplies may be deemed desirable.[16]

Merrill and Shanks[13] (1977) suggested that for best results for corrosion control, the alkalinity of the water should be maintained at least at 40 mg/l as $CaCO_3$ while maintaining a slight oversaturation of the water by 4-10 mg/l $CaCO_3$ within a pH range of 6.8 to 7.3.

Several investigators[17, 18, 19, 20] have reported that the addition of polyphosphates or silicates will stabilize the iron and prevent staining and red water problems. O'Connor[9], however, points out that heat causes polyphosphate to revert to orthophosphate, thereby destroying its sequestering ability. Further, this treatment technique should not be used when the original iron content exceeds 1 mg/l. If iron rust deposits are present in the distribution system, these can be loosened and dispersed in the water by sequestrants and create severe problems of rusty water. Hatch[21] and Moore and Smith[22] indicated that polyphosphates can also introduce lead into stagnant water from lead pipes, particularly at pH levels above 7 or 8. Larson[19] notes that polyphosphate additions may cause excessive bacterial growth in the distribution system, thereby creating a need for increased disinfectant residuals.

There are a number of alternatives available for controlling the corrosion of copper including the removal of dissolved oxygen by

deaeration, decreasing the carbon dioxide by pH adjustment, addition of inhibitors such as polyphosphates or silicates and maintenance of flow rates (below 4 feet per second) within the distribution system.[17] Table 3 presents a number of alternate treatment approaches for control of corrosion.

The cost of controlling corrosion represents a small increment in cost to a utility compared with significant benefit in (1) reduction of contaminants at the consumer's tap, (2) cost savings due to extending the useful life of distribution system materials, (3) energy savings in transporting the water due to the reduction of frictional losses, and (4) reduction of water losses through leakage or breakage.

The additional costs incurred by the implementation of a corrosion control program at a particular facility will be determined by the size of the facility, the particular treatment selected, the quality of the water distributed, increased monitoring requirements and additional workload of the staff.

Hudson and Gilcreas[1] estimated that the national annual costs of stabilizing corrosive waters would be approximately $27 million which in turn would result in an estimated economic savings of $375 million annually. The following information was used in deriving this estimate: 1) a total population of 180 million persons is served by community water systems; 2) investment in community water-distribution systems comprises about 60 percent of the capital cost of water utilities; 3) replacement cost of community systems is estimated to be $125 billion; sixty percent of the total is $75 billion; 4) even with stable waters, distribution capacity of new piping declines with age at a rate of 1 percent/year and with unstable waters, the decline commonly doubles, thus producing a further loss of 1 percent per year; and 5) half of the water supply systems have problems with corrosive water.

A specific MCL for corrosivity is not established at this time. Instead, the secondary regulations presently state that drinking water should be "non-corrosive." A non-specific corrosivity standard is warranted under the NSDWR because corrosive waters may adversely effect the aesthetic quality of drinking water. However, the existence of corrosive waters is left to be determined on a case-by-case basis through the exercise of judgment by the States in implementing the secondary regulations.

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Table 3 — Summary of Corrosion Treatment Techniques for Corrosion Control

Corrosion Treatment	Application	Effectiveness	Comments/Problems
Lime and Sodium bicarbonate or Lime	Increase pH Increase hardness Increase alkalinity Stabilize water	Most effective in water with low pH and hardness. Excellent protection for copper, lead and asbestos cement pipe in stabilized waters. Good protection for galvanized and steel pipe.	Best overall treatment approach. Oversaturation may cause calcium deposits. AWWA recommends 80 mg/l hardness as best.
Sodium hydroxide	Increase pH	Most effective in waters with sufficient hardness and alkalinity to stabilize water. May provide adequate protection against lead corrosion in low alkalinity soft waters.	Should not be used to stabilize waters without the presence of adequate alkalinity and hardness. Will cause dezincification of copper alloys at pH 9.0 to 9.6. May cause tuberculation in iron pipes at pH 7.5 to 9.0.
Sodium hydroxide and Sodium bicarbonate	Increase pH, Adjust alkalinity Stabilize water	Most effective in water with low pH and sufficient hardness. Excellent protection for lead corrosion in soft waters at pH 8.3.	Combination of high alkalinity and hardness with low pH is more effective than combination of high pH with low hardness and alkalinity.
Inhibition with phosphates	Formation of protective film on pipe surfaces.	Effective at pH levels above 7.0. Good protection for asbestos cement pipe. Addition of lime may increase effectiveness of treatment for copper, steel, lead and asbestos.	May cause leaching of lead in stagnant waters. May encourage the growth of algae and microorganisms. May cause red water if iron content is above 1 mg/l. May not be effective at low pH levels.
Inhibition with Silicates	Formation of protective film on pipe surfaces.	Most effective in waters having low hardness and pH below 8.4. Good protection for copper, galvanized and steel pipe.	May increase the potential of pitting in copper and steel pipes. May not be compatible with some industrial processes.

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Foaming Agents

Many substances in water will cause foam when the water is agitated or air is entrained as in a faucet. Foaming is an undesirable property of drinking water because it is aesthetically displeasing in that such agents impart an unpleasant taste, cause frothing and consumers often associate foaming with contamination. Because no convenient standardized foamability test exists and because surfactants are one major class of substances that cause foaming, this property is determined indirectly by measuring the anionic surfactant concentration in the water.

Surfactants are synthetic organic chemicals having high residual affinity at one end of their molecule and low residual affinity at the other. Its vigorous surface activity justifies not only its name but its use as a principal ingredient of modern household detergents. Surfactants may be divided into two broad chemical classifications, ionic and non-ionic. Ionic types may be either anionic (-) or catonic (+). Alkyl benzene sulfonate (ABS) and linear alkyl benzene sulfonate (LAS) are typical anionic surfactants.

Contamination of drinking water supplies by surfactants results from their disposal, as household and industrial wastes, into sources of raw water. Such contamination is appearing in both surface and ground water sources. Other potential sources of human intake of surfactants are food and inadequately rinsed cooking and household utensils and dinnerware.

More than 75 percent of the surfactants in household detergents are of the anionic type. Before 1965, alkyl aryl sulfonates accounted for almost three-quarters of these, the remainder being mostly alkyl sulfates. Next in extent of such use were the non-ionics, the cationics making up only a small percentage.[1] In recent years, the requirement for biodegradability led to widespread use of linear alkyl benzene sulfonate. Hence, the anionic group of surfactants is most apt to be present in raw water supplies.[2] It is largely for this reason that the degree of detergent contamination is established currently in terms of the concentration of anionic surfactants. While the currently-employed method for determination of the concentration of anionic surfactants (the methylene-blue method) measures more than anionic surfactants (most of the interferences are positive, some of which are foaming agents), this is not a problem at the levels usually encountered in drinking water.

Concentrations of anionic surfactants found in drinking waters range from 0 to 2.6 mg/l in well water supplies and from 0 to 5 mg/l in river water supplies. In one instance, a municipal water supply containing 5 mg/l during a period of drought necessitated use of an impounded, highly purified sewage treatment plant effluent as a raw water supply.[3]

In a study of the taste effects of surfactants[4], ten percent of the individuals using water containing less than 1 mg/l anionic sulfonate detergents complained of an off-taste, whereas all those using water containing 1.5 mg/l complained of an off-taste. Frothing was also a common complaint, occurring most frequently at concentrations of 1 mg/l and above. The off-taste has been described as oily, fishy, or perfume-like.[4] ABS and

LAS themselves are essentially odorless. The odor and taste characteristics are likely to arise from the degradation of waste products rather than the detergents. The concentration of ABS or LAS in municipal sewage averages 10 mg/l. Each mg/l of ABS or LAS present is an indication that 10 percent of the water in which the surfactant is detected is of sewage origin. Therefore, water containing the average concentration of 10 mg/l surfactant would likely be entirely of sewage origin.

From the basic toxicologic point of view, there are two reports which are especially pertinent to the present consideration:

1. The Toxicologic Subcommittee of the Food Protection Committee of the Food and Nutrition Board, National Research Council, published a comprehensive report in 1956[5] bearing on the question of surfactants in food. Reviewing extensively the acute and chronic toxic studies which have been reported on these chemicals, they found that there appears to be little specific relationship of toxicity to surface activity (reduction of interfacial tension). In conclusion it was stated that:
   a. There are no toxic effects common to all surfactants.
   b. Surface activity *per se* is not a measure of toxicity.
   c. The safety of each surfactant used in food must be determined separately.

   The report pointed out that surfactants may occur fortuitously in some foods in amounts of a few parts per million and that: "It appears probable that the interfacial tension existing in the digestive tract of a healthy human is so low that it will not be further lowered by the small amounts of synthetic surfactants which may be present in food."

2. In a report on an investigation dealing with the chronic and subacute toxicity to rats of several surface-active agents, among which was sodium alkyl aryl sulfonate, Fitzhugh and Nelson[6] declared that: "The toxic effects of the surface-active agents studied in the experiments were produced by irritation of the gastrointestinal tract (10,000 ppm or more in the diet). To an extent which depended on the concentration of the surface-active agents in the diet, this irritation prevented proper nutrition. In severe cases of irritation, death resulted."

An ABS or LAS concentration of 0.5 mg/l in drinking water, assuming a daily adult human intake of 2 liters, would give a safety factor of 15,000, calculated on the results of subacute[5] and 2-year[7] tests on rats fed diets containing ABS. In these rat studies, it was found that levels of ABS in the diet of 0.5 percent and below produced no discernible physiological, biochemical or pathological deviations from normal.

Human experience (6 subjects) with oral doses of purified ABS of 100 mg (equivalent to 2 liters of water containing 50 mg ABS/l) daily for 4 months led to no significant evidence of intolerance.[8] LAS has foaming characteristics similar to branched alkyl benzene sulfonate,[9] and it can be assumed that other properties are also similar.

Values for maximum anionic detergent concentrations in drinking water set by other agencies are as follows: World Health Organization's (WHO) International Standards – 1.0 mg/l[10]; WHO's European Standards

– 0.2 mg/l[11] ; proposed European Communities (EC) standards – 0.1 mg/l[12] .

Foaming substances can be removed by conventional treatment or by activated carbon. However, since the presence of foaming substances in drinking water is frequently an indicator of contamination by sewage, elimination of the source of contamination is the most appropriate treatment approach.

The secondary maximum contaminant level of 0.5 mg/l was based upon levels that would prevent the occurrence of visible foam as discussed above. Because of the association of other types of pollution with foaming substances, the appearance of visible foam should be immediately investigated and the source located and eliminated.

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Iron

Iron and manganese have similar adverse environmental effects and frequently occur together in natural waters. At one time, they were both covered by a single recommended limit. However, the 1962 Public Health Service (PHS) Standards[1] recommended separate limits for iron and manganese to reflect more accurately the levels at which adverse effects occur for each.

Iron is a highly objectionable constituent in water supplies for either domestic or industrial use. The domestic consumer complains of the brownish color that iron imparts to laundered goods and plumbing fixtures. Iron also appreciably affects the taste of beverages.[2] Taste thresholds in drinking water are considerably higher than the levels which produce staining effects.[3]

When the concentration of iron exceeds 0.05 mg/l, some color may develop, staining of fixtures may occur and precipitates may form.[4] The magnitude of such effects is directly proportional to the concentration of iron in water. Experience shows that concentrations somewhat higher than 0.05 mg/l may be generally tolerated. With certain exceptions, concentrations up to 0.5 mg/l may often be tolerated for industrial uses.[2]

The taste that iron imparts to water may be described as bitter or astringent. Individuals vary in the acuity of taste perception, and it is difficult to establish a level that would not be detectable for the majority of the population. In one study[5] 40% of a panel detected the taste of iron at 1.0 mg/l in spring water but its authors mentioned that an earlier researcher claimed 0.1 mg/l as the taste threshold for ferrous iron.

The daily nutritional requirement is 1 to 2 mg, but intake of larger quantities is required as a result of poor absorption. Diets contain 7 to 36 mg per day and average 16 mg.[6] The amount of iron permitted in water to minimize objectionable taste or staining effects (as much as 0.3 mg/l) constitutes only a small fraction of the amount normally consumed and does not have toxicologic significance.

Several investigators [3, 7, 8, 9] have reported that the addition of polyphosphates or silicates will stabilize the iron and prevent staining and red water problems. O'Connor[9], however, points out that heat causes polyphosphate to revert to orthophosphate, thereby destroying its sequestering ability. Further, he cautions against use of this treatment technique when the original iron content exceeds 1 mg/l. If iron rust deposits are present in the distribution system, these can be loosened and dispersed in the water by sequestrants and create severe problems of rusty water. Hatch[10] and Moore and Smith[11] indicated that polyphosphates can also introduce lead into stagnant water from lead pipes, particularly at pH levels above 7 or 8. Larson[8] notes that polyphosphate additions may cause excessive bacterial growths in the distribution system, thereby creating a need for increased disinfectant residuals.

Other maximum contaminant levels set for iron are as follows: WHO International Standards – 0.1 mg/l[12]; WHO European Standards – 0.1 mg/l[13]; USSR Standards – 0.5 mg/l[14]; proposed EC Standards – 0.3 mg/l[15]; and FDA Bottled Water Standards – 0.3 mg/l[16].

Iron can be removed by oxidation and conventional treatment and by an ion-exchange method specifically designed for iron removal. Utilization of the "manganese greensand" filter using potassium permanganate to oxidize the iron is also an effective method to remove iron. When the source of iron is the corrosion of pipes and other water-contact surfaces, stabilization or other appropriate water treatment processes can be employed to minimize introduction of iron into the water.

The secondary maximum contaminant level of 0.3 mg/l was determined to represent a reasonable level at which taste effects would be minimized in addition to minimizing the staining effects of iron. While the aesthetic effect of levels somewhat higher than 0.3 mg/l can be overcome by sequestration, there are drawbacks to the employment of this technique, as noted above.

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Manganese

Manganese and iron have similar aesthetic effects and frequently occur together in natural waters. At one time they were both covered by a single recommended limit, however, the 1962 PHS Standards[1] recommended separate limits for iron and manganese to reflect more accurately the levels at which environmental effects occur for each. There are two reasons for limiting the concentration of manganese in drinking water: (a) to prevent aesthetic and economic damage, and (b) to avoid any possible physiologic effects from excessive intake. The principal reason for limiting the concentration of manganese is to reduce the aesthetic and economic problems.[2,3,4] The domestic consumer finds that it produces a brownish color in laundered goods and impairs the taste of drinking water and other beverages including coffee and tea.[2,4] Taste thresholds in drinking water are considerably higher than the levels which produce staining effects.[5]

In concentrations of only a few hundredths milligram per liter, manganese may occasionally cause buildup of coatings in distribution piping. If these coatings slough off, they can cause brown blotches in laundry items and black precipitates. Griffin,[3] as chairman of a task group on "Manganese Deposition in Pipelines," stated that the concentration of manganese which could be tolerated by the average consumer is 0.01 – 0.02 mg/l. The World Health Organization (1970) suggests that such problems may arise at concentrations of manganese greater than 0.05 mg/l, the same limit recommended by the U.S. Public Health Service in 1962. In an unpublished survey of 13 States reporting on levels of manganese giving rise to water quality problems, only three States recommended levels as high as 0.2 mg/l, two permitted 0.15 mg/l and four each permitted 0.1 mg/l or 0.05 mg/l.[1] Domestic complaints generally arise when the level of manganese exceeds 0.15 mg/l but aesthetic problems can occur at lower levels. The application of chlorine increases the likelihood of precipitation of manganese at low levels; unless the precipitate is removed it can cause aesthetic problems.

From the health standpoint, data do not indicate at what level manganese would be harmful when ingested.[6,7,8,9] The principal toxic effects that have been reported are as a result of inhalation of manganese dust or fumes. It has been estimated that the daily intake of manganese from a normal diet is about 10 mg.[10] In animals, at least, it has been shown to be an essential nutrient, since diets deficient in manganese interfere with growth, blood and bone formation, and reproduction. Hepatic cirrhosis has been produced in rats when treated orally with very large doses. As far as is known, the neurologic effects of manganese have not been reported from oral ingestion in man or animal.[11] Ingestion of manganese in moder-

ate excess of the normal dietary level is not considered harmful. Concentrations of manganese found in water supplies are much less than those at which adverse health effects have been observed.[11]

Values for maximum manganese concentrations in drinking water set by other agencies are as follows: WHO International Standards – 0.05 mg/l[12]; WHO European Standards – 0.05 mg/l[13]; proposed European Community (EC) Standards – 0.05 mg/l[14]; and FDA Bottled Water Standards – 0.05 mg/l[15].

Manganese in concentrations greater than 0.05 mg/l may be sequestered by the addition of polyphosphates or silicates.[9, 16] However, Hatch,[17] and Moore and Smith[18] have indicated that polyphosphates can introduce lead into stagnant water from lead pipes, particularly at pH levels above 7 or 8. Larson[19] also notes that the polyphosphate additions may lead to excessive bacterial growths in the distribution system, thereby creating a need for increased disinfectant residuals.

In summary, manganese is similar to iron in that it can be sequestered to reduce its undesirable effects, but removal is preferable. Manganese can be removed by oxidation followed by filtration. The iron removal filter using "manganese greensand" is also effective for manganese removal.

The secondary maximum contaminant level of 0.05 mg/l was determined from the above data, is in agreement with other agency standards, and represents a level which prevents most aesthetic effects.

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Odor

The absence of taste and odor of water helps to maintain the consumer's confidence in the quality of their drinking water even though this does not guarantee that the water is safe. Industrial processes such as food, beverage and pharmaceutical manufacturers, require water essentially free of taste and odor. Taste and odor tests are also useful as a check on the quality of raw and finished water, for control of odor through the plant and the determination of treatment dosages. Odor is also useful as a test of the effectiveness of different kinds of treatment, and as a means of tracing the source of contaminants.

According to psychologists, there are only four true taste sensations: sour, sweet, salty and bitter. Dissolved inorganic salts of copper, iron, manganese, potassium, sodium and zinc can be detected by taste. Concentrations producing taste range from a few tenths to several hundred milligrams per liter. As these tastes are not accompanied by odor, the taste test must be used where they are involved.

All other sensations ascribed to the sense of taste are actually odors, even though the sensation is not noticed until the material is taken into the mouth. Odor tests are performed to arrive at qualitative descriptions and approximate quantitative measurements of odor intensity. Odor tests are less fatiguing than taste tests; hence, an operator can conduct odor tests for a longer period. Higher temperatures can be used for odor evaluations than for the taste test, with a resultant increase in sensitivity on some samples.

Some organic and inorganic chemicals contribute both taste and odor. These may originate from municipal and industrial waste discharges, natural sources (such as decomposition of vegetable matter), or from associated microbiological activity. Because some odorous materials are detectable when present in only a few micrograms per liter and are often complex, it is usually impractical and often impossible to isolate and identify the odor-producing chemical.

Burttschell, Rosen, Middleton and Ettinger[1] showed that chlorine, when combined with phenol, produces particularly odorous chlorophenolic compounds. Further, they showed that about 20 percent of the original phenol concentration was present as 2,4-dichlorophenol 18 hours following chlorination, while 25 percent was present as 2,6-dichlorophenol after the same period. Table 1 shows the odor threshold concentration for phenol and its chlorinated products.

More recently, the AWWA Committee on Tastes and Odors reported on odorous natural metabolites.[2] Both geosmin and mucidone have been suggested as causative agents of musty odors produced from algae and actinomycetes. Rosen, Mashni and Safferman[3] isolated and identified geosmin and 2-methylisoborneol from carbon-chloroform extracts collected from two Ohio lakes exhibiting odors.

The Threshold Odor Number (TON) of water is the dilution factor required before the odor is minimally perceptible. A TON of 1 indicates that the water has characteristics comparable to odor-free water, while a TON of 4 indicates that a volume of the test water would have to be diluted to 4 times its volume before the odor became minimally perceptible. For precise work, a panel of five or more testers is required, and the TON is based on the greatest amount of dilution which elicits a positive odor response from one of the testers.

The following maximum odor levels have been established by other agencies: Proposed European Community Standards – 2 TON at 12° C and 3 TON at 25° C[6]; FDA Bottled Water Standards – 3 TON[7]. While other agencies recommend testing regularly for odor levels, these agencies have not established limits.[8]

The control of odor in water requires knowledge of the nature of the odorous material. Oxidative processes are effective when the odor is due to sulfide, chlorophenols, and many other substances. Activated carbon is effective against some odors of organic origin.

Table 1 — Odor Threshold Concentrations

Compound	Odor Threshold Concentration – ug/l			
	Burttschell, et al.[1,4]	Baker[4]	de Grunt[4]	Zoeteman[5]
Phenol		5,900		5,900
2-chlorophenol	2		0.2	0.2
4-chlorophenol	2	1,240	0.5	
2,4-dichlorophenol	2	210		210
2,6-dichlorophenol	3		7.5	8
2,4,6-trichlorophenol	1,000			

The secondary maximum contaminant level of 3 TON was determined to be the odor level that most consumers would find acceptable, and is in agreement with other agency standards as noted above.

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pH

Natural waters used as drinking water sources range from highly alkaline ground waters to very acidic surface waters. Although from a health standpoint a wide range of pH values for drinking water can be tolerated, a low

pH may cause the need for heavier chlorination, whereas a high pH may cause increased halogen reactions. Both excessively high and low pH's may cause increased corrosivity and an unpleasant taste. These considerations suggest employment of a narrower pH range.

At low and high pH's, water tends to be corrosive, in that it tends to dissolve materials with which it is in contact. When metallic piping is in contact with water of low pH, some of the metal is dissolved, imparting a metallic taste to the water in some instances. If the metal is iron or copper, oxides and carbonates will be deposited, leaving red or green stains, respectively. If the metal is lead or galvanized (containing lead and cadmium as impurities), there may be no apparent corrosive effect, but the water will contain potentially hazardous amounts of these toxic metals.

Many factors may influence the corrosivity of water in addition to low pH but it is a sufficiently common factor to merit recommending a minimum level. Water below a pH level of 6.5 will usually be corrosive.[1]

At high pH's, drinking water acquires a bitter taste. The high degree of mineralization often associated with alkaline waters results in encrustation of water pipes and water-using appliances.

In addition the disinfection activity of chlorine falls significantly as pH levels rise.[2] For example, several times as much chlorine is required for a 100 percent kill of *Salmonella typhosa* (currently called *S. typhi*) at a pH of 9.8 as against a pH of 7.0.

High pH levels also appear to have an accelerating effect on the haloform reaction which produces chloroform and other trihalomethanes during chlorination.[3] Constraint of this reaction is certainly a desirable objective.

While a number of factors, in addition to high pH, influence taste, encrustation, disinfection and the formation of trihalomethanes, it was determined that a maximum level of 8.5 is a reasonable goal. The WHO has set the lower limit at a pH of 7.0[4], whereas, the European Communities have proposed a range of 6.5 to 8.5.[5]

Adjustment of pH is accomplished by addition of alkaline or acidic chemicals such as sodium hydroxide, lime, soda ash, carbon dioxide and sulfuric acid.

The secondary maximum contaminant level for pH is therefore the range 6.5 to 8.5. Corrosive properties are minimized by setting the lower part of the pH range at 6.5 and the higher part of the pH range of 8.5 minimizes the other problems associated with higher pH values.

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Sulphates

There are three reasons for limiting the concentration of sulfates in drinking water: (a) waters containing appreciable amounts of sulfate tend to form hard scales in boilers and heat exchangers; (b) sulfates cause taste effects; and (c) sulfates can cause physiological effects (i.e., laxative effects) with excessive intake.[1]

Both sodium sulfate and magnesium sulfate are well known laxatives. The laxative dose for both Glauber salts ($Na_2\ SO_4\ 10H_2O$) and Epsom salts ($MgSO_4\ 7H_2O$) is about two grams. Two liters of water with about 300 mg/l of sulfate derived from Glauber salt, or 390 mg/l of sulfate from Epsom salt, would provide this dose. Calcium sulfate is much less active in this respect.

The laxative effect is commonly noted by newcomers and casual users of water high in sulfates. One evidently becomes acclimated to use of these waters in a relatively short time.

The North Dakota State Department of Health has collected information on the laxative effects of water as related to mineral quality. This has been obtained by having individuals submitting water samples for mineral analysis complete a questionnaire that asks about the taste and odor of the water, its laxative effect (particularly on those not accustomed to using it), its effect on the flavor of coffee, and its effect on potatoes cooked in it. Peterson[2] and Moore[3] have analyzed part of the data collected, particularly with regard to the laxative effect of the water. Peterson found that, in general, waters containing more than 750 mg/l of sulfate showed a laxative effect while those with less than 600 mg/l generally did not. Moore showed that laxative effects were experienced by the most sensitive persons, not accustomed to the water, when magnesium was about 200 mg/l and by the average person when magnesium was 500-1,000 mg/l. Moore analyzed the data as shown in Table 1. When sulfate plus magnesium exceed 1,000 mg/l, a majority of those who gave a definite reply indicated a laxative effect. No other adverse health effects have been noted for concentrations less than about 500 mg/liter. The only observed physiological effect at higher concentrations has been the induction of diarrhea.[1]

Table 2 presents some data collected by Lockhart, Tucker and Merritt[4] and Whipple[5] on the influence of sulfate on the taste of water and coffee. Because of the milder taste of sulfate over chloride,[6, 7] the taste of sulfate would probably initially be detected in the 300-400 mg/l range, but some people are able to detect taste at the 200 mg/l level.[1] The Peterson data[2] and Table 1,[3] however, indicated that from 600 to 1,000 mg/l of sulfate has a laxative effect on a majority of users. The data indicate that no significant taste effects occur at 200-300 mg/l.

Values for maximum sulfate concentrations in drinking water set by other agencies are as follows: WHO International Standards – 200 mg/l[8]; WHO European Standards – 250 mg/l[9]; proposed EC Standards – 250 mg/l[10]; and FDA Bottled Water Standards – 250 mg/l[11].

Sulfate cannot be readily removed from drinking water without use of distillation, reverse osmosis or electrodialysis which are effective but rela-

tively expensive; thus, the use of an alternate source or blending are the most desirable approaches.

The secondary maximum contaminant level of 250 mg/l was determined as the level which would prevent most taste effects. This SMCL will also prevent the undesirable laxative effects even in most casual consumers.

Table 1 — Water Quality of Wells as Related to Presence or Absence of Laxative Effects (Moore[3])

Determination	Range mg/l	Number of Wells in Range	Laxative Yes	Laxative No	Effects Present Not Stated	Percent of Yes Answers *
Magnesium plus sulfate	0-200	51	9	34	8	21
	200-500	45	7	27	11	21
	500-1,000	56	11	38	17	28
	1,000-1,500	36	18	10	8	64
	1,500-2,000	14	6	4	4	60
	2,000-3,000	21	13	3	5	81
	Over 3,000	14	5	1	8	83
Sulfate	0-200	56	10	36	10	22
	200-500	47	9	28	10	24
	500-1,000	56	13	26	17	33
	1,000-1,500	34	16	10	8	62
	1,500-2,000	16	9	4	3	69
	2,000-3,000	20	9	3	8	75
	Over 3,000	8	3	0	5	100

*This percentage is based only on the total of yes and no answers. It is probable that a large proportion of the wells for which no statements were made were not regularly used as water supplies.

Table 2 — Data on the Influence of Sulfate Salts on the Taste of Water and Coffee (Lockhart, et al[4]; Whipple[5])

	Threshold Concentration – mg/l			
	Median		Range	
Salt	Salt	Anion	Salt	Anion
Na_2SO_4	350	327	250-550	169-372 (4)
$CaSO_4$	525	370	250-900	177-635 (4)
$MgSO_4$	525	419	400-600	320-479 (4)
	Average			
$MgSO_4$	500	400 (5)		

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Total Dissolved Solids

A SMCL for total dissolved solids (TDS) was established because high concentrations have adverse taste effects which force consumers to use other water sources. Highly mineralized water also deteriorates distribution and domestic plumbing and appliances.

It should be emphasized that there may be a great difference between a detectable concentration and an objectionable concentration of the neutral salts. The factor of acclimatization is particularly important. A number of public supplies in the United States provide water with more than 2,000 mg/l of dissolved solids. Newcomers and casual visitors would certainly find these waters almost intolerable and although some of the residents use other supplies for drinking, many are able to tolerate (and possibly enjoy) these highly mineralized waters.

Recent data from Bruvold, et al.[1] have demonstrated that more acute taste effects occur as the total mineral content rises. Pangborn, et al.[2] have also shown that the temperature of the water influences the acceptability of mineralized waters. One study is cited[3] as showing that families using

waters with TDS concentrations ranging from 500-1750 mg/l expressed dissatisfaction with their supply and turned to bottled water as an alternate source. Waters containing TDS concentrations in the range of 10,000 mg/l are considered unusable for drinking.

Mineralization has been shown to have an economic impact on water distribution systems and household plumbing and appliances.[4] According to Lawrence[5], the life of home hot water heaters decreases one year for each additional 200 mg/l of TDS in water above a typical 200 mg/l figure.

Mineralization can also cause precipitates to form in boilers or other heating units, sludge in freezing processes, rings on utensils and precipitates in foods being cooked.

The 1962 edition of the Public Health Service Drinking Water Standards[3] included a limit for total dissolved solids (TDS) of 500 mg/l because of taste effects and because drinking water containing a high concentration of TDS was likely to contain an excessive concentration of some specific substance that would be aesthetically objectionable to the consumer. The WHO International Standard and the FDA Bottled Water Standard are also set at 500 mg/l.[6] The AWWA recommended quality goal is 200 mg/l.[7]

The use of alternative sources and/or blending are recommended when dissolved solids exceed the SMCL. The available treatment processes (distillation, reverse osmosis, electrodialysis) are effective but relatively expensive.

The secondary maximum contaminant level of 500 mg/l was determined to represent a reasonable goal which would prevent most aesthetic effects of dissolved solids.

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Zinc

Although zinc is an essential and beneficial element in human metabolism[1,2], excessive amounts in drinking water may produce adverse physiological and taste effects, a milky appearance, and may increase lead and cadmium concentrations.

The daily requirement for preschool-age children is 0.3 mg Zn/kg. Total zinc in an adult human body averages 2 grams. Zinc content of human tissues ranges from 10-200 ppm wet weight; the retina of the eye and the prostate contain the largest concentrations (500-1,000 ppm). Three percent of all blood zinc is in the white cell. The daily adult human intake averages 10-15 mg; excretion of zinc averages about 10 mg in the feces and 0.4 mg in the urine. Zinc deficiency in animals leads to growth retardation. This can be overcome by adequate dietary zinc. The activity of several body enzymes is dependent on zinc.

A group of individuals stationed at a depot used a drinking water system containing zinc at 23.8 to 40.8 mg/l and experienced no known harmful effects. Communities have used waters containing from 11-27 mg/l without harmful effects.[3,4] Another report[5] stated spring water containing 50 mg/l was used for a protracted period without noticeable harm. On the other hand, another supply containing approximately 30 mg/l was claimed to cause nausea and fainting.

Zinc salts act as gastrointestinal irritants. Although the illness is acute, it is transitory. The emetic concentration range in water is 675-2,280 mg/l. A wide margin of safety exists between normal intake from food and water and those quantities likely to cause oral toxicity.

Zinc compounds also impart taste to drinking water. In tests performed by a taste panel, 5 percent of the observers were able to distinguish between water containing 4 mg/l (when present as zinc sulfide) and water containing no zinc salts. The water was described as having a bitter or astringent taste. Soluble zinc salts at 30 mg/l may impart a milky appearance to water, and at 40 mg/l, a metallic taste.[6]

Cadmium and lead are common contaminants of zinc used in galvanizing. Assuming that zinc is dissolved from galvanized water pipe no less than cadmium, dissolution of zinc to produce 5 mg/l would be accompanied by something less than the allowable 0.01 mg cadmium per liter when cadmium contamination of the zinc is as high as 0.03 percent. Likewise, lead concentrations would likely be increased by something less than the allowable 0.05 mg/l when lead contamination of the zinc is as high as 0.6 percent. An AWWA statement cites two States as having a zinc limit of 1.0 mg/l and recommends 1.0 mg/l as a water quality goal.[7]

Values for maximum zinc concentrations in drinking water set by other agencies are as follows: WHO International Standards – 5 mg/l[8]; WHO European Standards – 5 mg/l[9]; FDA Bottled Water Standards – 5 mg/l[10]; USSR 16 hours standard – 1.0 mg/l[11]; and the proposed EC standards – 2.0 mg/l[12] (16 hours standard).

The principal source of zinc in drinking water is the dissolution of galvanizing by aggressive waters. Such dissolution can be minimized by stabilization or neutralization. If zinc is a constituent of the source water, conventional treatment may be effective.

The secondary maximum contaminant level of 5 mg/l was determined to be the level which would prevent most taste problems.

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